AN ACOUSTIC ANALYSIS OF THE 1988 SONG OF THE HUMPBACK WHALE, *MEGAPTERA NOVAEANGLIAE*, OFF EASTERN AUSTRALIA

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This paper presents an acoustical analysis of the 1988 Humpback Whale song off east coast Australia, particularly of the sound types which comprise the song. The analysis shows that the song represented generally a well structured form, broadly similar to that of 1982/83, even though there was a change to a less structured song in 1984 (Cato, this memoir). A relatively detailed analysis of the structural components of the song, specifically the sound types, has been undertaken. Although the song is relatively stereotyped, variation in the acoustical characteristics of the sound types is observed which may be significant in terms of structural components of the song. The full range structural complexity in the Humpback Whale song may not be fully known. ☐ *Humpback Whale, song, marine acoustics, animal behaviour, marine mammals.*

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Payne and McVay (1971) recognised that Humpback Whale sounds recorded off Bermuda occurred in fixed patterns to form songs. They found that individual sound units were grouped to form phrases which were repeated to form themes. This ordered sequence comprised the song.

Based on studies of Humpback Whale songs in eastern Australian waters since 1979, Cato (1984, this memoir) established the existence of song structures that were broadly similar to those of the Northern Hemisphere. The song of 1982/83 was well structured with six themes, but a rapid change in 1984 lead to a relatively poorly structured song. Cato introduced the concept of "sound type" as a means of categorising the sound units according to acoustical characteristics. He found that sound units of the 1982/83 song could be classified into 12 types.

I present here an analysis of the 1988 song off eastern Australia with particular emphasis on the characteristics of sound types. These are given descriptive names which are definitive to this paper. Sound types are classified according to acoustical characteristics and some of the subtleties in variation of characteristics are addressed.This may allow interpretation in greater detail and contribute to functional understanding of structural components of the song. Cato (1984) noted that, because the song is stereotyped, its potential to carry information is limited. Information transmission depends on variations in the song.

METHODS

Song recording

Song data for 1988 were collected by Dr D. Cato, during the southward migration, 2–4 October, 1988, off Stradbroke Island latitude 27°S. This was close to the peak time of the southward migration as identified by Chittleborough (1965) and confirmed by Paterson and Paterson (1989). Recordings were made from a 3m motor boat, using a hydrophone at about 20m depth, a preamplifier, a Sony Walkman Professional WMD6 tape recorder. The frequency responses are uniform within ±3dB over the frequency range 50 Hz–15 kHz.

Song analysis

Song analysis involved aural and spectrographic analysis. Most of the energy of Humpback Whale sounds lies in the range 100–4000 Hz and the sounds are distinctive to our ears (human hearing is within the range of c. 20Hz–20kHz). A considerable amount of analysis of the song structure was therefore done aurally by noting down sound units sequentially using graphic symbols, where each symbol represents a sound type, thus identifying the order and timing of sound units, phrases, themes and song

TABLE 1. Phrase structures of the 1988 song.

THEME	SOUND UNITS IN ORDER OF OCCURRENCE	OCCUR-RENCES
1	n-chug	19-28
	zp	1
	oink	1
2	n-chug evolve into whistles	11–12
	cry	2
	n–whistles	17–20
	cry	5–8
	n–whistles	3–4
	cry	3–12
3	up moan	3
	n–violin	1
	coarse roar	2
	down moan	1
4	up moan	1
	down moan	1
	up moan	1
	down moan	1
	up moan	1
	flat roar	1
	moan staccato	5–4
	screal	1
5	up moan	1
	down moan	1
	up moan	1
	down moan	1
	up moan	1
	flat roar	1
	hmm	5–7
	screal	1
6	up moan	1
	down moan	1
	up moan	1
	down moan	1
	up moan	1
	flat roar	1
	whoomp	5–8
	screal	1
7	whoomp	2
	chain-saw growl	1

cycles. The aural analysis was repeated until the song structure was fully established. This involved a detailed analysis of the data, looking for patterns in the occurrence of the sound units. Sound units were grouped to form phrases and similar phrases were then grouped into themes. As patterns were established, they were checked for consistency between the different song cycles of an individual singer and between the songs of presumably different singers. Acoustical characteristics for each sound type and phrase structure were determined from sonagrams produced on a Kay Elemetrics sonagraph.

Seventeen hours of recorded data were analysed, which included 64 song cycles able to be analysed. Intensity levels for different sound units were determined with a Bruel and Kjaer level recorder type 2305, played through a Rockland low pass filter, to remove unwanted low frequency noise.

RESULTS

Song Structure

The 1988 song structure (Table 1) comprises 7 themes in a fixed order, where each theme comprises a particular phrase with a variable number of renditions. This is a well structured song, similar to that of 1982/83 (Cato,1984,this memoir). It has 7 themes and 15 sound types compared with 6 themes and 12 sound types in 1982/83. This shows that the song off east Australia has returned to a well structured form after the change to a relatively poorly structured song in 1985. On average, the song consists of about 160 sound units, depending on the number of phrase and sound unit renditions in different themes.

The Humpback Whale song is complex and relatively stereotyped; considerable analysis may be done in the description and interpretation of the song characteristics. Even though the song is relatively stereotyped, there are certain subtleties in the complex song which are not stereotyped.

Description of the Sound Types.

The frequencies of all sound types is in the range 50–8000Hz (more than 7 octaves), the lowest in frequency being the "whoomps" and "down moan" and the highest in frequency being the "n-whistles" and "screal" (Table 2). In the 1988 song the range in the fundamental frequency was 50–4000Hz while Payne and Payne (1985) observed a range of 30–4000Hz in songs in Bermudan waters over 19 years.

The sound types vary from acoustically simple to complex and are classified into four categories (Table 2). These categories are determined from sonagrams and are audibly quite distinctive. Each category can be subdivided according to the frequency range, fundamental frequency and

TABLE 2. General sound type spectral and temporal characteristics.

SOUND TYPE	FREQUENCY RANGE (Hz)	FREQUENCY OF FUNDAMENTAL OR LOWEST S.L.* (Hz)	NO. OF HARMONICS /S.L.*	TIME (s)
HARMONIC				
– rising frequency				
n-whistles	600-8000	600–3000	2–5	0.1–0.3
cry	500–7500	500–700	10–11	0.3–1.35
up moan	200–4000	200–350	2–<16	0.8–1.7
n-violin	100–6000	100	2	0.6
oink	150–2500	150	7	0.4
– falling frequency				
down moan	50-5500	50–200	2–19	0.8–2.2
– steady frequency				
hmm	120-4000	120–250	5–16	0.45–0.7
– collective				0.9–1.7
BROAD BAND WITH SPECTRAL LINES				
coarse roar	400–3750	400–600	2–8	1.2–4.45
flat roar	250–4500	250–350	4–20	0.8–2.4
chain saw growl	100–4000	100–1000	6	3.0–5.7
screal	900–8000	900–1450	3–8	2.0–3.5
BROAD BAND IMPULSIVE				
zp	2000	80	7	0.5
n-chugs	80–6000	impulsive	6	0.2–0.35
COMPLEX				
– moan staccato				1.1–3.0
moan	100–5000	100–340	3–15	0.8–1.8
staccato	300–6800	300–450	3–12	0.3
– whoomp				
harmonic	50–1300	50–100	5–11	0.3–0.5
impulsive	600–4000	50–4000	impulsive	0.1–0.5
– pulse	600–4000	600–1100	pulsation	0.1–0.2

*S.L. = spectral lines

duration. The harmonic sound types "cry" and "up moan", and the complex sound type "moan staccato" (Table 2) (which is actually a combination of two harmonic sounds) have similarities; however, differences in fundamental frequencies, frequency contour on the sonagram and duration separate them (Figs 1–3). The "coarse roar" and "flat roar" (Table 2) are similar; however, the former has a higher fundamental frequency range. The "down moan" is distinctive relative to all other sound types (Fig. 4).

Harmonic sound types with a rising frequency

The "cry" sound type is representative of this subcategory (Fig. 1). It lasts 0.3–1.35 secs depending on its position in the phrase in theme 2, the only theme in which it occurs. Silences between cries range from 1.1–2.8 secs.

The "up moan" occurs in 4 different themes with some variation in the sound character between different themes and within the same phrase of a theme depending on the position of the sound unit in the phrase, i.e. inter theme and intra phrase variation (Figs 2,4). This variation

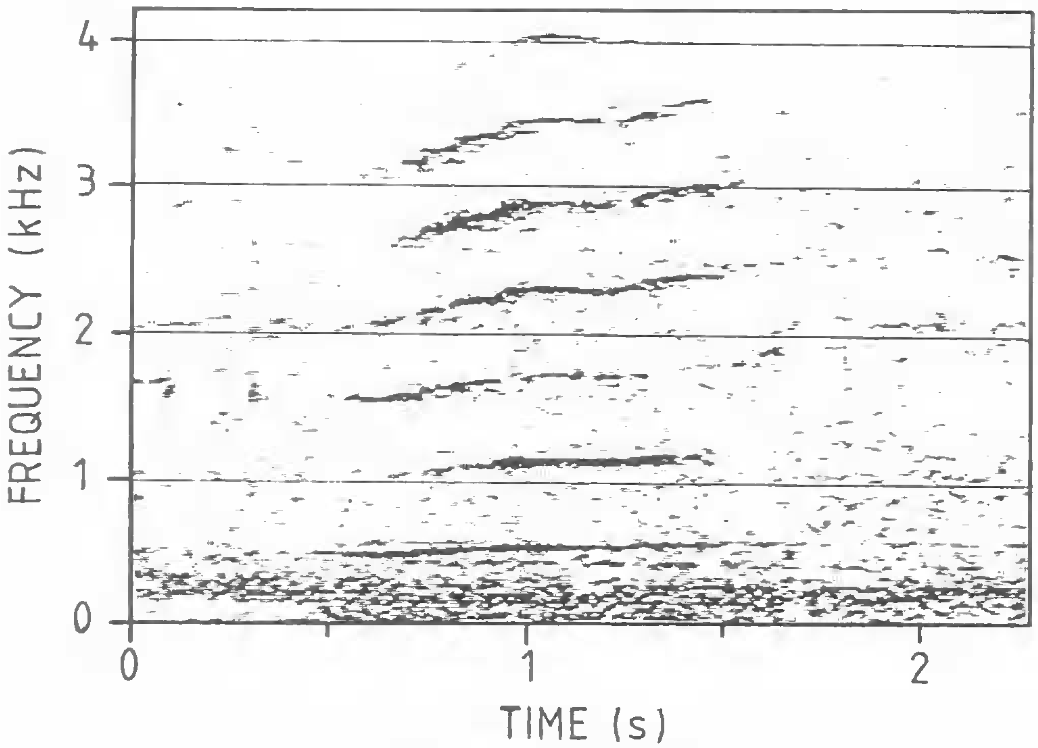

FIG. 1. Sonagram of an harmonic with a rising frequency sound type "cry".

is in the fundamental frequency and duration. The duration of the sound type ranges from 0.6–2.1 secs. Silences of following units in themes 4 and 5 are 1.5–1.9 secs.

Harmonic sound types with a falling frequency

The "down moan" (Table 2) occurs in four different themes with some variation in fundamental frequency and duration between themes (Fig. 4).

Broad band with spectral lines not harmonically related

These sound types are not harmonic but have energy spread over some bandwidth, and spectral peaks evident as spectral lines. The frequencies of these lines are not harmonically related. The "screal" (Table 2) has 3–10 spectral lines (Fig. 5) and occurs once in 3 different themes, consistently as the last sound unit in a phrase. Sound character variation in the different themes is shown in Table 3.

The "chain saw growl" (Table 2) generally occurs at a number of frequencies between 100 and 1600 Hz (Fig. 6). It generally increases in duration with each phrase rendition in the theme. The sound type occurs singularly in the phrase of theme 7.

Harmonic sound types with a steady frequency

The "hmm" (Table 2) occurs in a group of units, like the "n-chugs", where 2–4 sound units

TABLE 3. Variation of "screal" between themes.

THEME	FREQUENCY RANGE (Hz)	FUNDAMENTAL FREQUENCY (Hz)	NO. OF SPECTRAL LINES	TIME (s)
4	900–8000	900–1400	3–10	2.5–3.5
5	900–5500	900–1400	3–6	3.0–3.3
6	1000–6800	1000–1450	5–8	2.0–3.0

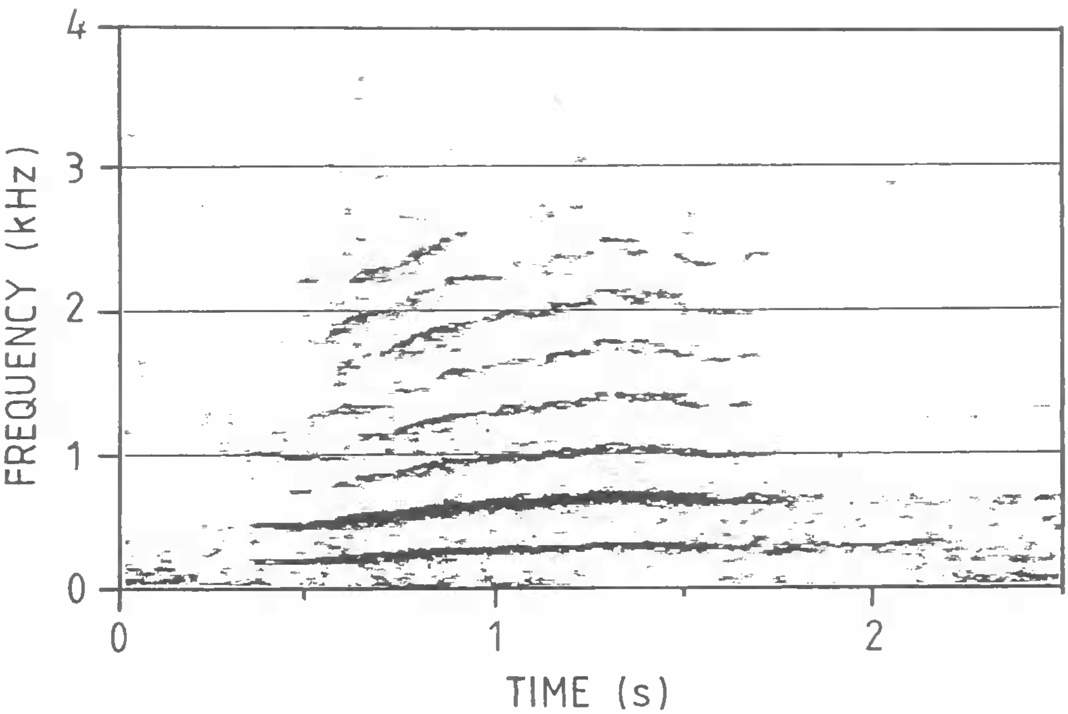

FIG. 2. Sonagram of an harmonic with a rising frequency sound type "up moan".

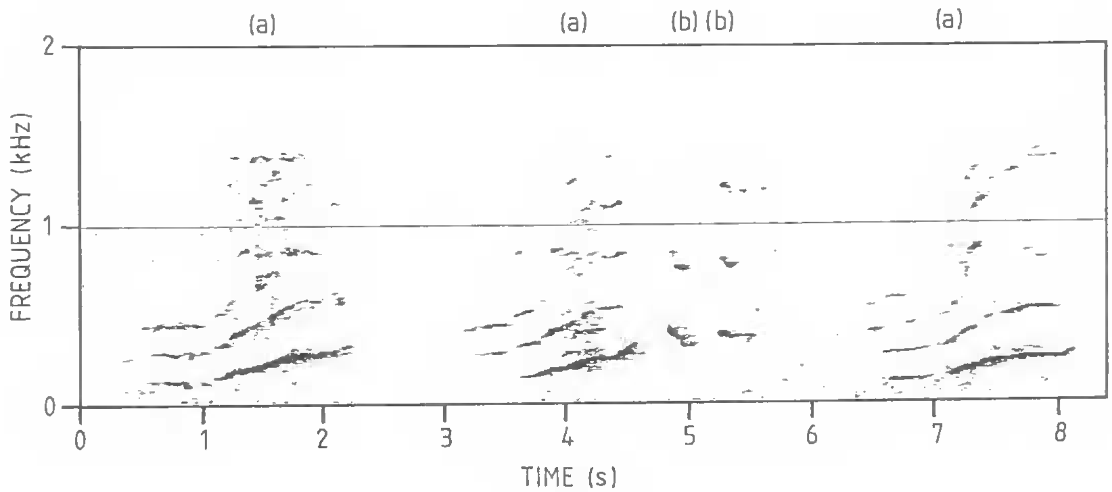

FIG. 3. Sonagram of a complex sound type "moan staccato" including a, moan and b, staccato endings.

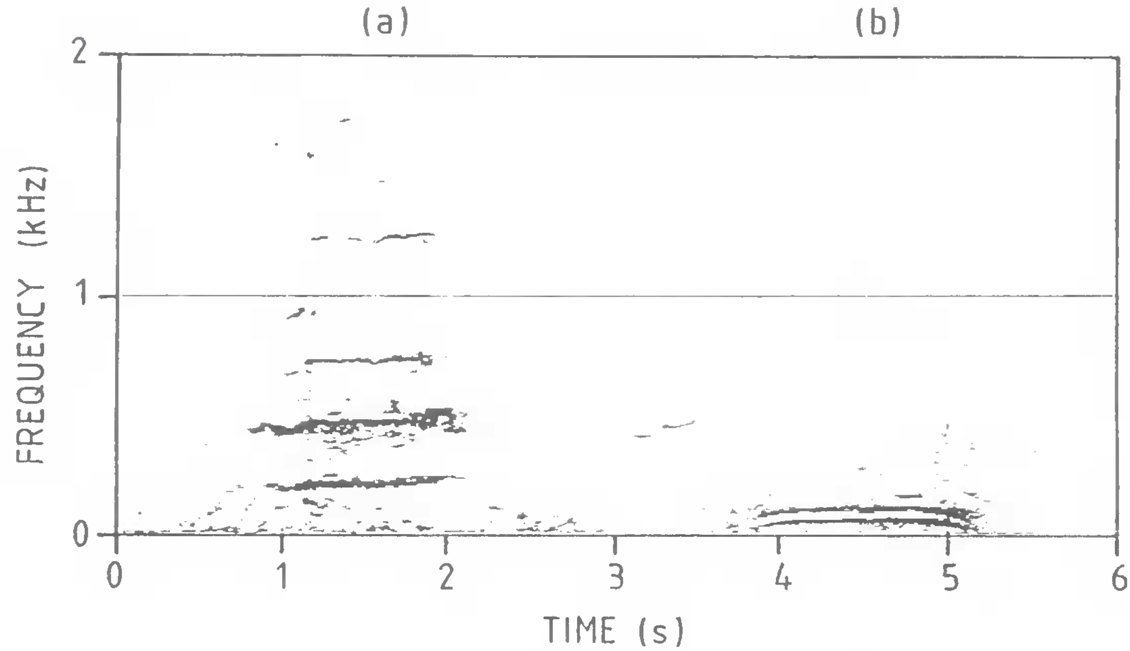

FIG. 4. Sonagram of an harmonic with a falling frequency sound type a, "up moan" and b, "down moan".

may occur in one group. For example, (hmm hmm hmm) (hmm hmm hmm hmm) (hmm hmm hmm), where each hmm represents one rendition of the sound unit. Each sound unit is 0.45–0.7 secs in duration while a collective group may extend 0.9–1.7 secs. The period of silence between units of the same group is c. 0.05–0.1 secs and between groups there are longer silences of 0.4–0.9 secs. It occurs in theme 5 only.

Broad band impulsive sound types

The impulsive sound types are the "n-chugs", occurring in themes 1 and 2 and "zp" occurring in theme 1. The "zp" occurs only once in the phrase of theme 1.

The "n-chug" sound type occurs as a collective unit. For example a collection of "n-chugs" may comprise 28 sound unit repetitions in a particular pattern i.e. (111) (1111) (1111) (11111)

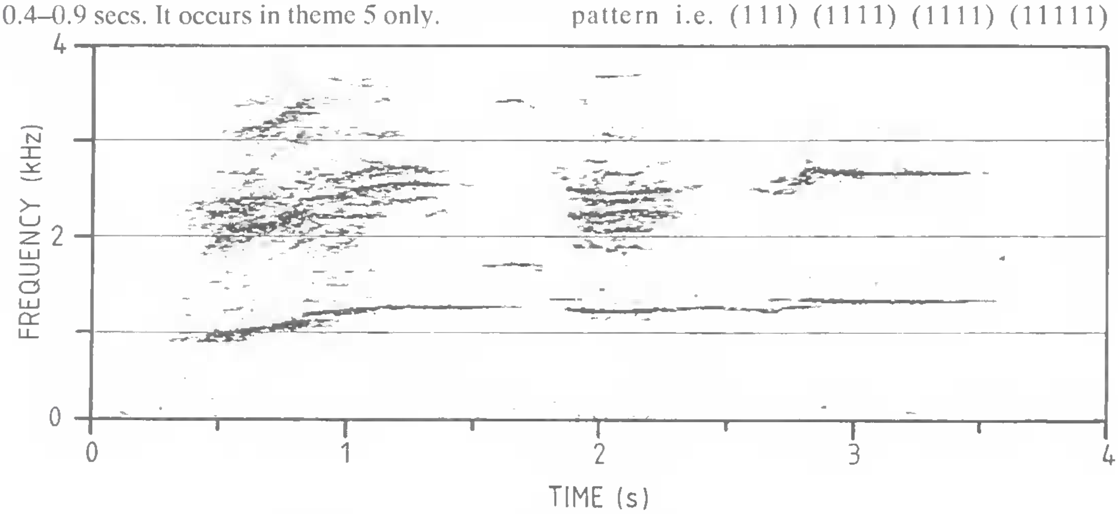

FIG. 5. Sonagram of a broad band with spectral lines sound type "screal".

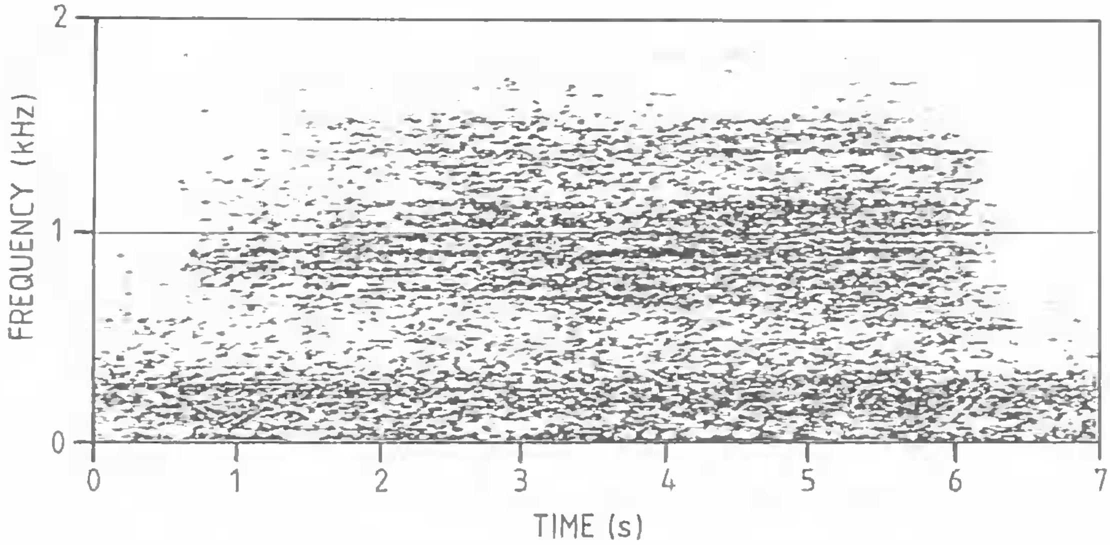

FIG. 6. Sonagram of a broad band with spectral lines sound type "chain-saw growl".

(111111) where 1=1 chug. So that the whole collective consists of subgroups each with a variable number of chug repetitions (Fig. 7). These units are impulsive in structure with most energy between 80–2000Hz and extending to 6000Hz. Silences of 0.20–0.55 secs between subgroups and 0.15 secs between renditions of units within one group were observed.

Complex sound types

Complex sound types are combinations of components which may be harmonic or impulsive. The "whoomp" sound type starts as a harmonic and evolves to an impulse with a pulsating, "possum" ending (Fig. 8). This sound type occurs in themes 6 and 7 with sound character variation between these themes being of a lower frequency, less harmonic in structure and without the terminal impulse in theme 7. While in theme 6 the impulse ending may or may not occur.

It is evident from the above discussion that

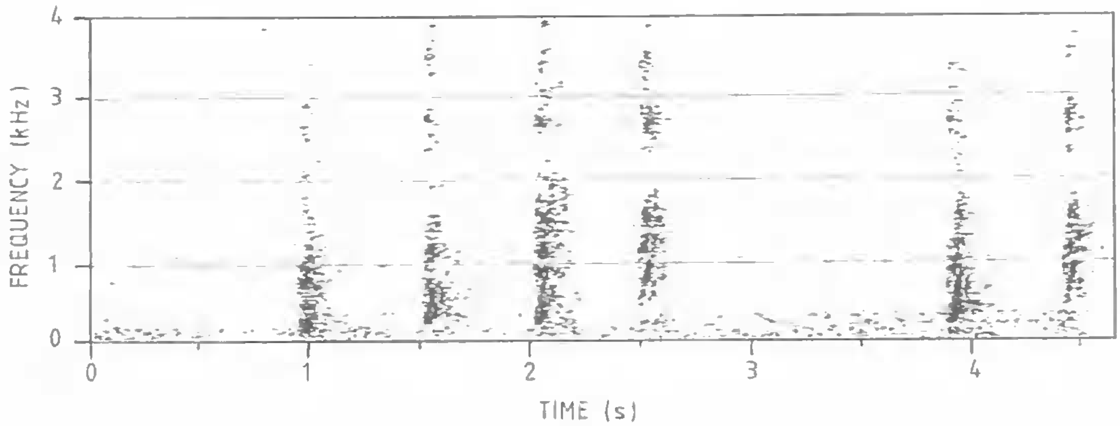

FIG. 7. Sonagram of a broad band impulsive sound type "n-chugs".

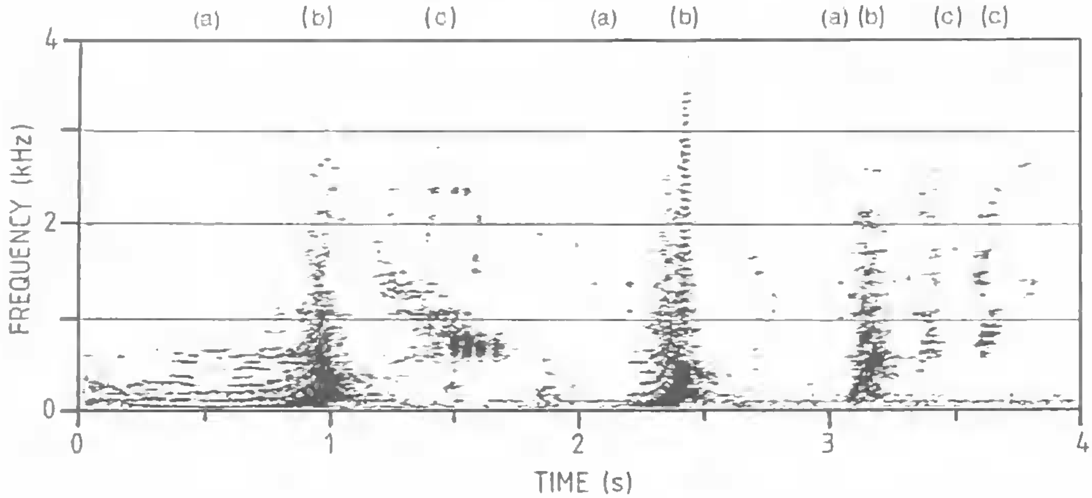

FIG. 8. Sonagram of a complex sound type - "whoomp", including (a) harmonic, (b) impulse, and (c) pulsating ending.

there are variations in the characteristics of the sound types in the song.

Duration of the Sound Types

Sound types vary in duration from 0.1–5.7 secs, the shortest being the "n-whistles" (theme 2) and the longest being the "chain saw growl" (theme 7). Cato observed sound type durations of 0.1–4.3 secs in the 1982 song, where the "whistles" were the shortest and the "chain saw" the longest. However, the "chain saws" of the 1982 song are not the same sound type as the "chain saw growls" in the 1988 song. In Bermudan waters the longest sound type was 8 secs and the shortest <2% of the longest (Payne and Payne 1985).

Variation in Sound Type Abundance and Distribution throughout the Song

The sound types are variable in terms of distribution through the different phrases of the song (Table 1). Some sound types are particular to certain themes i.e. "zp" and "oink" to theme 1 and "n-whistle" to theme 2, whilst other sound types are relatively ubiquitous, i.e. "up moan", "down moan", "screal" and "flat roar", occurring in three different themes and the "whoomp" occurring in two different themes.

Nine of the sound types occur more than once in a phrase. The remaining occur only once in a phrase, for example "n-violin" in theme 3 and, "screal" and "flat roar" in themes 4, 5 and 6.

Variation in Sound Type Character - Inter-Theme and Intraphrase Variation

As sound types are repeated throughout a phrase or as they occur in different themes, the sound character (e.g. a slight change in fundamental frequency, frequency range or duration) may vary depending on the sound type's position in the song. For example, in theme 4 the "up moan" is emitted 3 times, each rendition becoming shorter. However, the same sound type in theme 5 is generally shorter in duration. Additionally, the "moan staccato" may vary in sound character with repetition in a phrase of theme 4, and the number of staccato units may vary with each repetition. The staccato endings are mostly present but sometimes absent. Similarly, the "whoomp" in theme 6, is represented with "possum-like" endings in some phrases but not in others.

The character of a sound type may therefore change with respect to its position in the phrase or in the song. Although there are subtle variations in the character of a particular sound type, the sound types are generally similar from one rendition of the song to the next. Even though there is some variation in the acoustical character of a sound type, this variation is small compared to the differences in acoustical characteristics between different sound types.

Perhaps these observed variations can be related to accentuation of meaning i.e. possibly these variations have specific functions in terms of communication and general behaviour of the singer. A slight modification in the sound type may change the signification of the signifier i.e. the meaning of the sound type.

Sound Intensity

From a limited sample of 6 song cycles over 2 days, intensity varied between different sound types. The "moan staccato" has the highest level of all sound types while the "flat roar", "hmm" and "screal" are the next highest. These are mean values and not always consistent with each phrase rendition. It is important to consider this feature relative to overall rhythm (Guinee and Payne, 1988) and possible "accentuation" of certain sound units. Additionally, sound level diminishes at theme 7, which may be due to attenuation of sound when the whale approaches the surface to breath (Tyack,1981).

Silences between Sound Units

In the 1988 song, silences between sound units of up to 3.2 secs were observed where the longest silences generally occurred between sound units of themes 1 and 7. Shortest silences were c. 0.15 secs between "n-whistles" in theme 2 and 0.2 secs between "n-chugs" in theme 1. Payne and Payne (1985) observed silences as very short or lasting up to 6 secs. The range in duration of silences between sound units may be important structural features of the song.

CONCLUSIONS

The 1988 song of east Australia shows a well-developed structure similar to that in the 1982-early 1984, compared to the "unstructured" song of 1985.

The 1988 song consisted of 15 sound types. Sound types representative of particular acoustical groups are described with regard to spectral and temporal characteristics, showing the differences between sound types and between renditions of the same sound type. The analysis indicates that while the sound types do not vary to a great extent with different song renditions, there are subtle variations with renditions of the same sound type which may contribute to the overall function of the song, for example the information content. It is possible that these subtleties function as components of the song structure. A more detailed analysis of the song structure and the sound units may reveal the function of these structures and thereby contribute to the understanding of the song.

This paper presents an analysis of the song at a certain level of magnification, however, it is not fully understood whether this level of detail is at a scale appropriate to the Humpback Whale physiological sensory apparatus. It is yet to be determined how representative these identified song components are for communication. Analysis of these structural details may lead to a greater understanding of Humpback Whale song evolution, learning capacity and behaviour, and the role of song in the reproductive success and possible social structure of the species.

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